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Acoustic wave dispersion and scattering in complex marine sediment structures

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LONG TERM GOALS

The long term science goals are to understand and quantify the physical mechanisms that control propagation and scattering in the seabed.

OBJECTIVES

The objectives are to advance understanding of 1) the nature and mechanisms leading to sediment volume scattering and 2) the effects of shear waves in general layered media. These advances will provide the basis for measuring dispersion in *in-situ* sediments in the frequency range of interest, 0.1-10 kHz. This work builds on prior research in disentangling the effects of sedimentary layering and sound speed/density gradients [1].

APPROACH

The approach includes both theoretical as well as measurement components. Theory is needed to better understand the relationship between sediment volume scattering from a continuum (e.g., slumps and slides) versus scattering from discrete particles (e.g., rocks, shells, or bubbles). Measurements are needed to 1) exploit the volume scattering theory for identification of the dominant mechanisms and seabed features that give rise to volume scattering and 2) to quantify the effects of various mechanisms, including volume scattering and shear waves on dispersion in marine sediments. The first step will be development of the theory.

WORK COMPLETED

A brief summary of the work completed follows:

- From a mathematical standpoint, sediment volume heterogeneities can be described either by a fluctuation continuum or by discrete particles. In at-sea experiments, heterogeneity characteristics generally are not known *a priori*. Thus, an uninformed model selection is generally made, i.e., the researcher must arbitrarily select either a discrete or continuum model. It was shown (see Ref [2]) that it is possible to (acoustically) discriminate between continuum and discrete heterogeneities in some instances. The ability to so discriminate is important, because there are few tools for measuring small scale, O(10^{-2} to 10^{1}) m, sediment

heterogeneities over large areas. Therefore, discriminating discrete vs continuum heterogeneities via acoustic remote sensing may lead to improved observations and concomitant increased understanding of the marine benthic environment. The research results are described in detail in Ref [2] and are summarized in the results section.

- Preparation for two at-sea experiments:
    - ONR SCA16 experiment planned for Spring 2016. This is the first ONR sediment acoustics experiment to focus on muddy fabrics (clays and silty clays). Part of the preparation for this experiment has been the analysis and processing of prior data sets that the PI collected when he was in residence at the NATO SACLANT Centre (now CMRE) in environments with a significant mud component. The analyses are being conducted in collaboration with colleagues at the University of Victoria including Stan Dosso, Jan Dettmer and Jorge Quijano.

    - GLISTEN2015 (lead by J.M. Jiang, CMRE). This experiment will employ gliders and ship-based measurement techniques for seabed characterization in the northern Tyrrhenian Sea in August-September 2015. The experiment with take place in an area that exhibits a mud layer approximately 10 m thick at the 100 m bathymetric contour and a few tens of cm at the 130 m contour. The planned data collection offers an opportunity to advance understanding of mud geoacoustic properties as well as to refine measurement techniques in muddy environments, which is expected to be of value in preparation for the ONR SCA16 experiment.

RESULTS

A brief review is provided of the theoretical work in volume scattering (see Ref [2] for details). Sediment heterogeneities are nearly ubiquitous and lead to the scattering of acoustic waves from the sediment volume. The main question addressed was whether it is possible from acoustic backscattering or reverberation measurements to determine the class, i.e., whether the scattering is due to a continuum or from discrete heterogeneities.

It was shown that in some instances it is possible to discriminate between classes. For a general layered seabed, discrimination between classes is possible via the spectral exponent, γ_3. When $\gamma_3>4$, the volume scattering cannot be described by discrete particles. Conversely, when $\gamma_3\leq 2$, the heterogeneities likely arise from discrete particles. Furthermore, in the range $2<\gamma_3\leq 4$ where both continuum and discrete classes are plausible, parameter relationships between the two classes were developed in order to enable potential discrimination by parameter values, i.e., determining whether the values are physical or reasonable. In particular relationships were quantified between: 1) the spectral cut-off length and the discrete particle radius and 2) the continuum spectral strength and various discrete parameters including the volume fraction and the ratio of material parameters.

Whereas these results were obtained first under the assumptions of spherical heterogeneities and fluid media, it is shown in Ref [2] that the results were considerably more general and also apply to non-spherical and elastic heterogeneities.

Importantly, the theoretical results formed the basis for developing a discrimination methodology. The methodology is a step-wise logical application of discrimination tests to measured data (scattering or

reverberation) in order to discern whether the heterogeneities form a continuum or are discrete. The main results of the research serve to provide a framework for designing and planning experiments as well as analyzing the observations.

The main theoretical results of Ref [2] were derived by equating the discrete and continuum formalisms at low and high frequency asymptotes. One example of (and check on) the theoretical relations is shown in Fig 1. This figure shows scattering from a (power law) distribution of discrete particles (solid line). Using the theoretical relations derived in [2], the parameters for the equivalent continuum case (assuming a von Karman spectrum) are obtained, which when used in the continuum model yields the red dashed line (spectral). Both curves have the identical low and high frequency behavior (indicating that the relationships developed are correct).

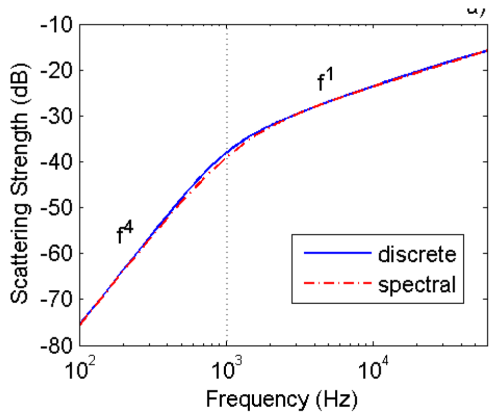

Figure 1. Comparison of scattering strength from a continuum (red dash-dot) and discrete (blue solid) sediment volume heterogeneities for a wide range of particle sizes, a_2/a_1=100 where a_1 , a_2 are the inner and outer scales respectively. The vertical line dotted that separates the two regimes is at $ka_2=1$.

IMPACT/APPLICATIONS

In the long term, the theoretical relationships developed for volume scattering will improve our understanding of the marine benthic environment: what kind of scatterers are important, are they best described by a discrete or a continuum approach? The ability to so discriminate is important, because there are few tools for measuring small scale, O(10^{-2} to 10^{1}) m, sediment heterogeneities over large areas. The results show that an acoustic remote sensing approach is capable in some cases of discriminating which kind of heterogeneities are responsible for the sediment scattering.

In the shorter term, the results are important for re-examining recent volume scattering analyses [3] in several continental shelf environments. While the analysis in [3] assumed that the heterogeneities were described by a continuum with an outer scale of O(10^{-1}) m, the current research will link those results to a discrete scatterer hypothesis. The importance of this is that the outer scale controls the frequency dependence of scattering and reverberation of active sonar systems. Furthermore, understanding the geologic origins of the outer scale could lead to a greater prediction capability for those systems.

RELATED PROJECTS

ONR shallow water field experiments, e.g., SCA16: the advances here will motivate experiment design to distentangle effects of sediment dispersion from other frequency dependent effects.

OAML Mid-frequency Bottom Scattering Database. A prototype database was developed under sponsorship of PMW-120 drawing on 6.1 fundamental research on bottom scattering and reverberation. This database will replace the current default, Lambert's Law, in one area of operational interest. Though the database is expected to transition to OAML shortly with subsequent extension to other regions of interest planned, there are several 6.1 questions about the nature of the scattering mechanism that are important to answer, particularly for the question of spatial extrapolation. Some of the questions addressed in the above are expected to have direct relevance to database provincing and parameter extrapolation.

REFERENCES

[1] Holland C.W. J. Dettmer, In-situ sediment dispersion estimates in the presence of discrete layers and gradients, J. Acoust. Soc. Am., 133, 50-61, 2013.

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[3] Holland C.W., Evidence for a common scale O(0.1) m that controls seabed scattering and reverberation in shallow water, J. Acoust. Soc. Am., 132, 2232-2238, 2012.

PUBLICATIONS

Holland C.W., G. Steininger and S. Dosso, Discrimination between discrete and continuum scattering from the sub-seafloor, J. Acoust. Soc. Am., 138, 663-673, 2015. [published, refereed]